Plasma Sources for EUV Lithography

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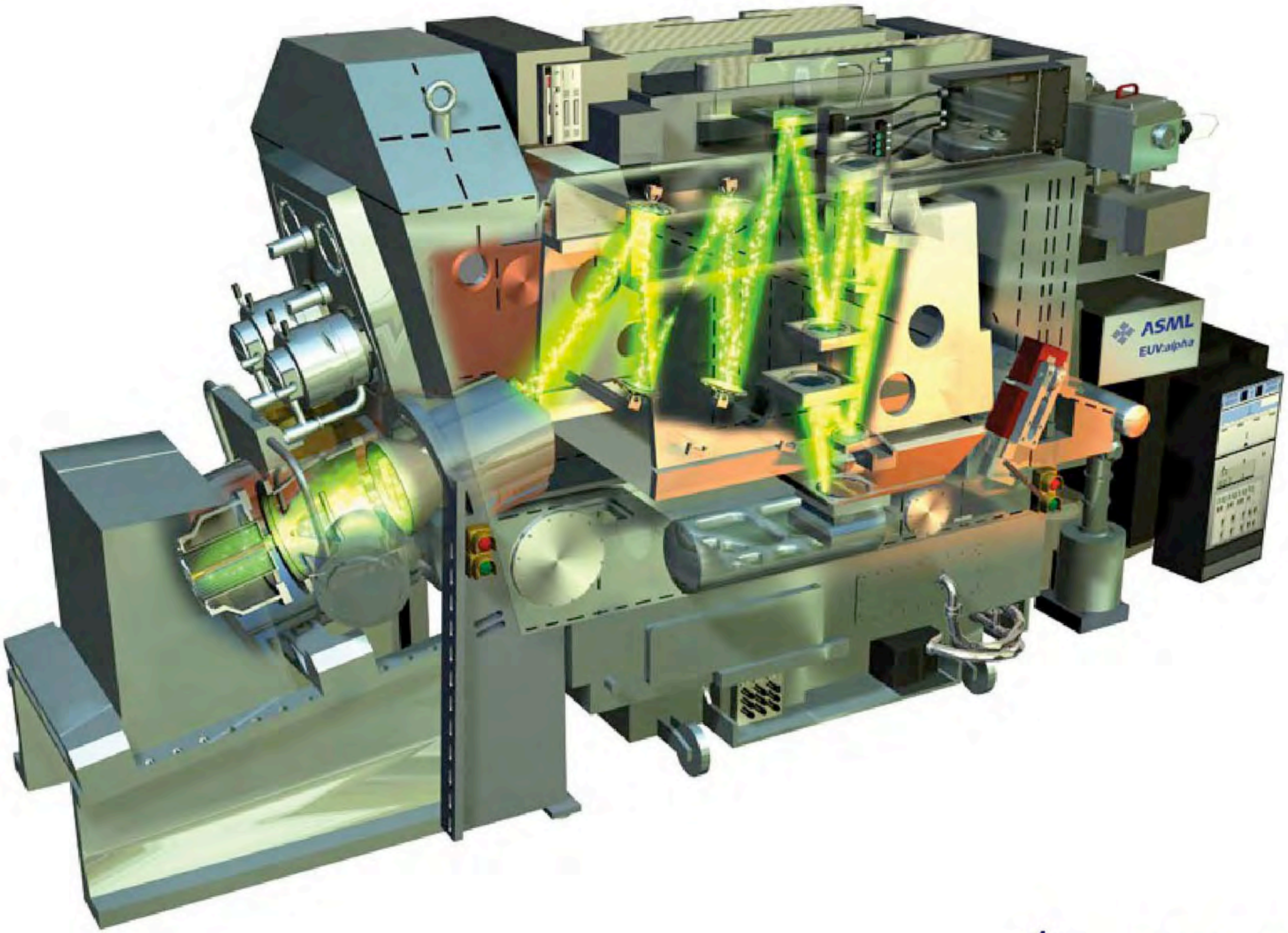
(http://www.coe.berkeley.edu/AST/sxr2009)

The ASML EUV alpha demo tool

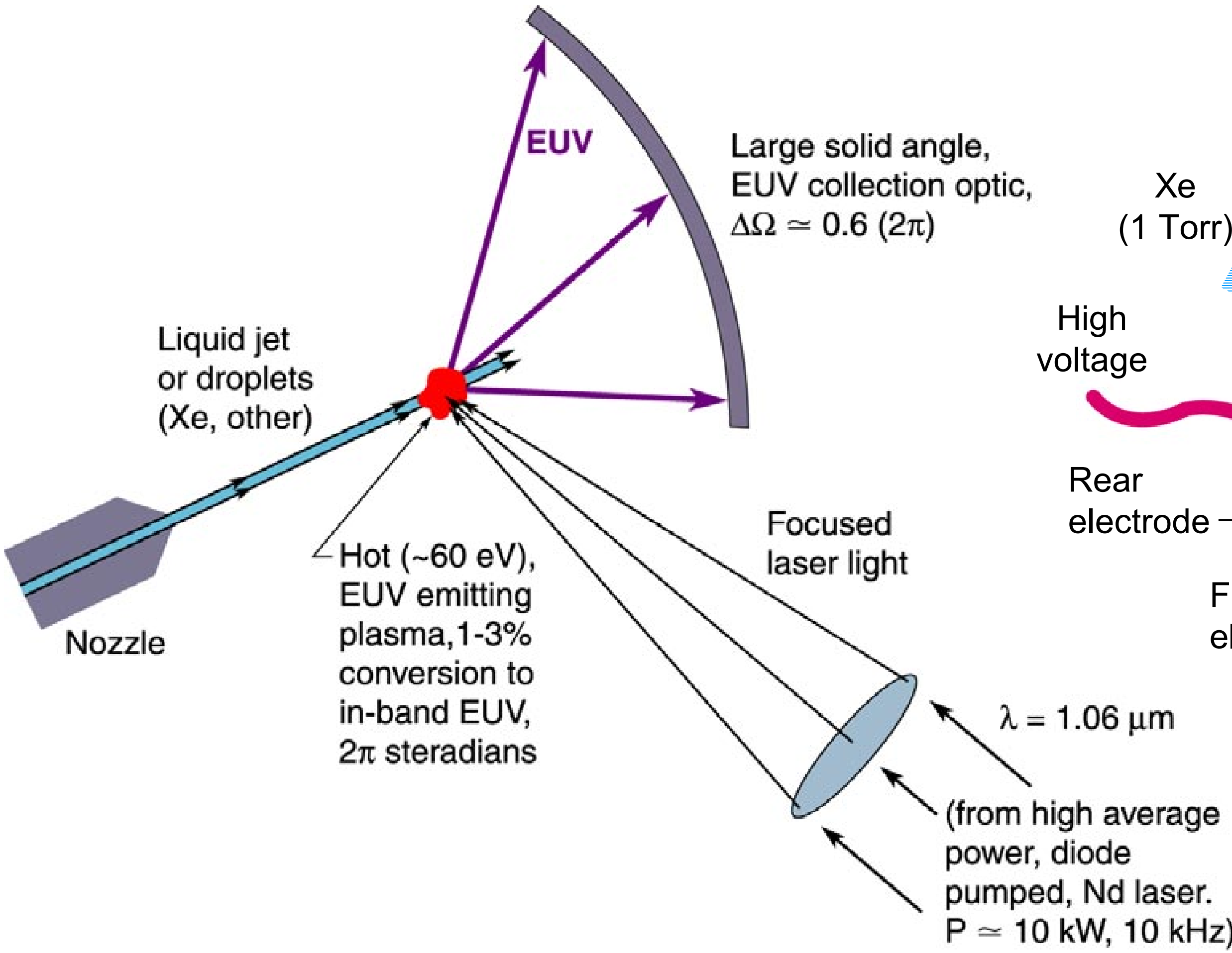


Courtesy of Dr. Hans Meiling, ASML

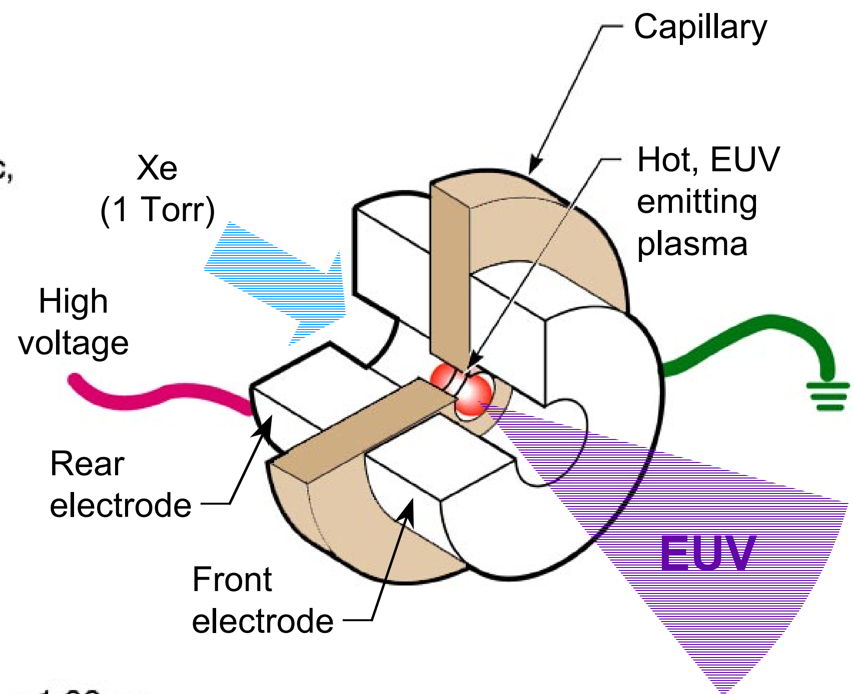
ASML

EUV Source Candidates for Clean, Collectable 13-14 nm Wavelength Radiation

Laser Produced Plasma Source



Electrical Discharge Plasma Source



Courtesy of Neil Fornaciari and Glenn Kubiak, Sandia.

J. Phys. D: Appl. Phys. (London) **37**, 3207(2004)

Plasma sources for EUV lithography exposure tools

Vadim Banine and Roel Moors

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doi:10.1088/0022-3727/37/23/001

Abstract
The source is an integral part of an extreme ultraviolet lithography (EUVL) tool. Such a source, as well as the EUVL tool, has to fulfil extremely high demands both technical and cost oriented. The EUVL tool operates at a wavelength in the range 13–14 nm, which requires a major re-thinking of state-of-the-art lithography systems operating in the DUV range. The light production mechanism changes from conventional lamps and lasers to relatively high temperature emitting plasmas. The light transport, mainly refractive for DUV, should become reflective for EUV. The source specifications are derived from the customer requirements for the complete tool, which are: throughput, cost of ownership (CoO) and imaging quality. The EUVL system is considered as a follow up of the existing DUV based lithography technology and, while improving the feature resolution, it has to maintain high wafer throughput performance, which is driven by the overall CoO picture. This in turn puts quite high requirements on the collectable in-band power produced by an EUV source. Increased, due to improved feature resolution, critical dimension (CD) control requirements, together with reflective optics restrictions, necessitate pulse-to-pulse repeatability, spatial stability control and repetition rates, which are substantially better than those of current optical systems. All together the following aspects of the source specification will be addressed: the operating wavelength, the EUV power, the hot spot size, the collectable angle, the repetition rate, the pulse-to-pulse repeatability and the debris induced lifetime of components.

Table 2. Throughput case study.

EUV power (in-band, 2π)	1.0 kW
Transmission and collection efficiency	0.02%
Resist sensitivity	5 mJ cm^{-2}
Exposure time per wafer	23 s
Scan speed	170 mm s^{-1}
Throughput	100 wph

EUV Source Power Requirements are Set by Wafer Throughput Models

Updated EUV power and wafer throughput:

250 W

~~120~~ W

120 wafers/hr

Collectable EUV power ~~60~~ W
EUV Power @ reticle 3.5 W
Power @ wafer 140 mW
Illum. time per field 0.26 s
Illum. time per wafer 23 s
Raw wafer throughput ~~80~~ wafers/hr

Collectable, in-band, "clean" (no debris, no out-of-band)

10

~~5~~ mj/cm^2 resist

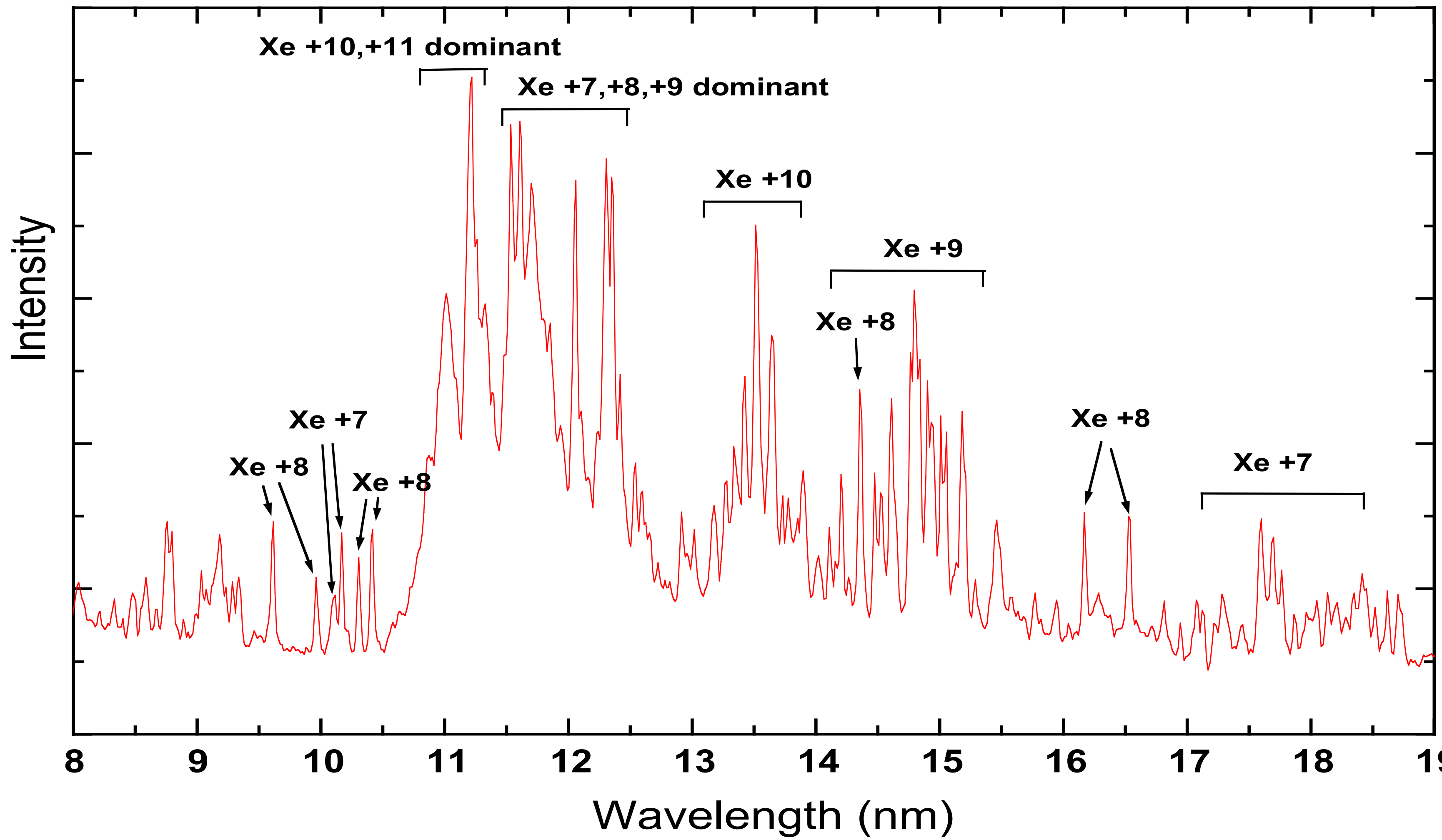
300 mm wafers

89 fields/wafer

Original courtesy of Jos Benschop and Vadim Banine, ASML.

J. Benschop et al., SPIE *3997*, 34 (2000),
V. Banine and R. Moors, SPIE *4343*, 203 (2002).

Typical EUV Spectrum from a Xenon Plasma in a Capillary Electrical Discharge



References:

Blackburn J, Carroll P, Costello J and O'Sullivan G 1983 *J. Opt. Soc. Am.* **73** 1325

Gayasov R and Joshi Y 1998 *J. Phys. B* **31** L705

Kaufman V and Sugar J 1984 *J. Opt. Soc. Am.* B **1** 38

Kaufman V, Sugar J, and Tech J 1983 *J. Opt. Soc. Am.* **73** 691

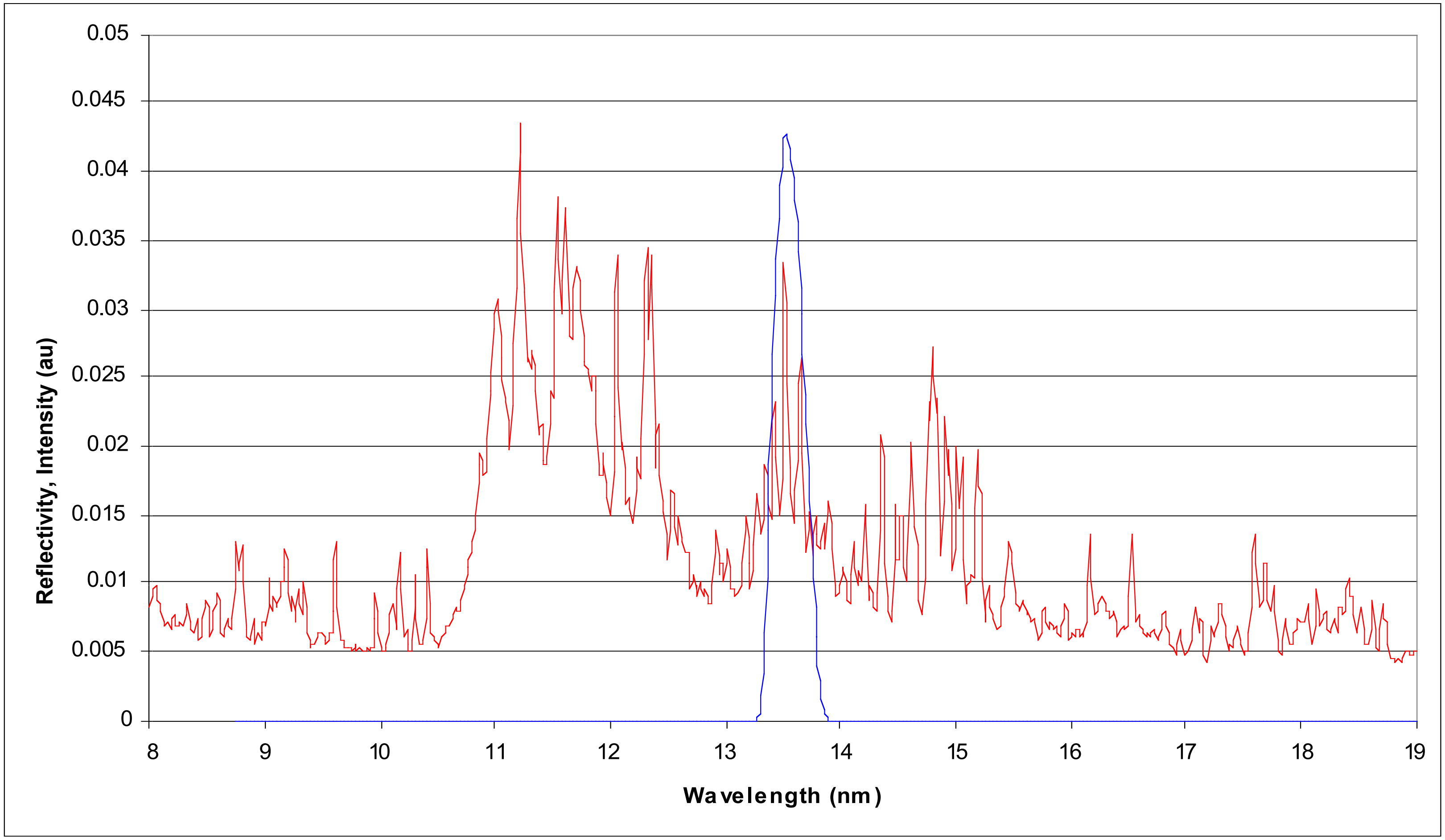
Sugar J and Kaufman V 1982 *Physica Scripta* **26** 419

O'Sullivan G 1982 *J. Phys. B* **15** L765

Sandia National Laboratories

Jason Dimkoff AST 213

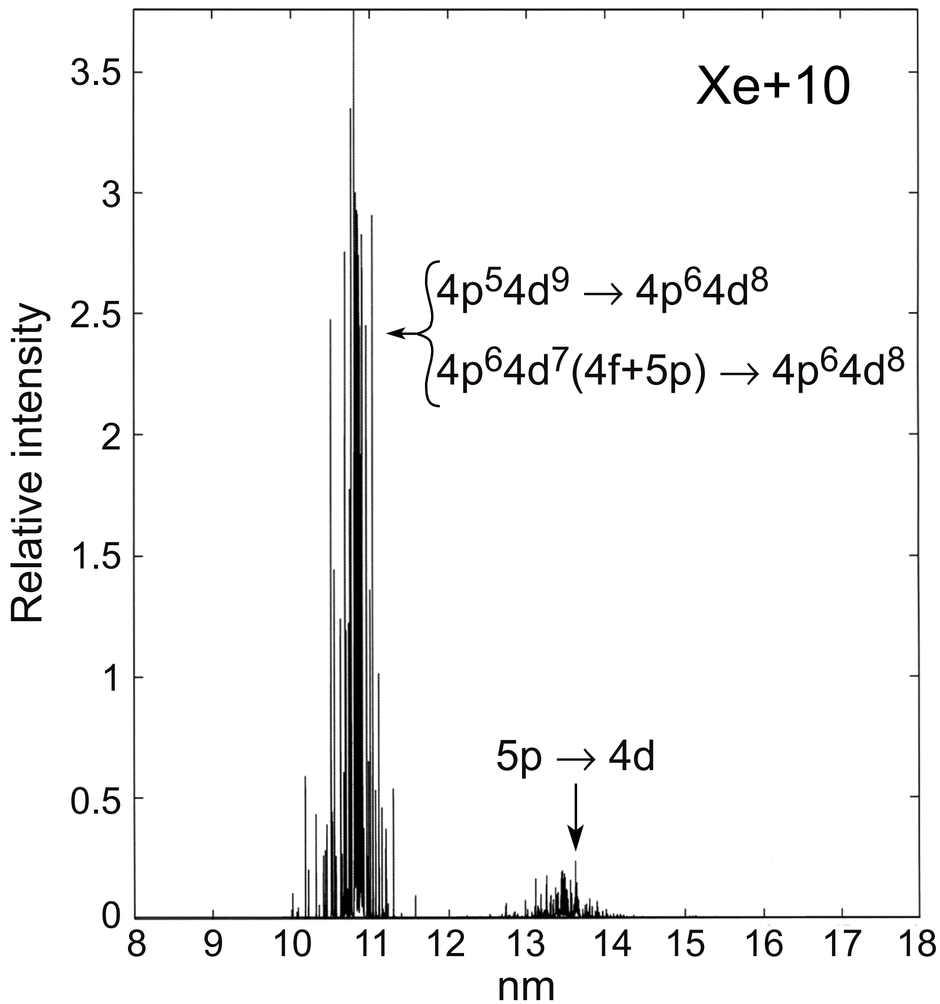
EUV Spectrum of Capillary Discharge With Nine Mirror System Reflectivity



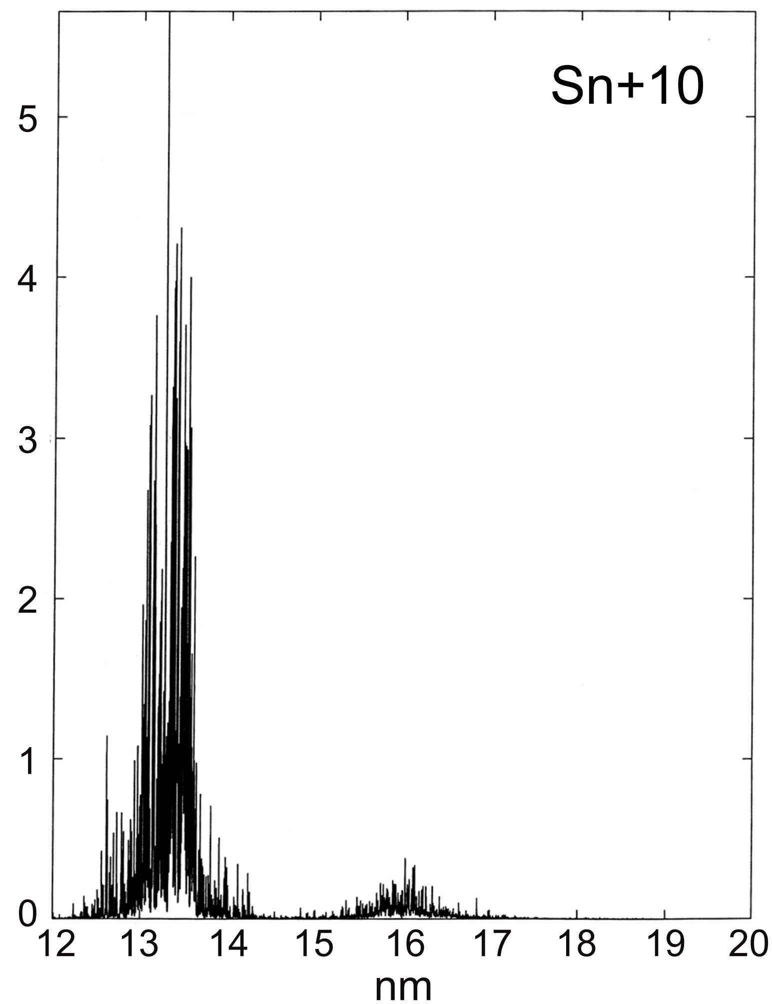
Multilayer Mirror Parameters:
40 bilayers, σ=0.5 nm rms, Γ=0.44, FWHM of curve centered at 13.5nm

Comparative Spectra: Xe and Sn

Xenon



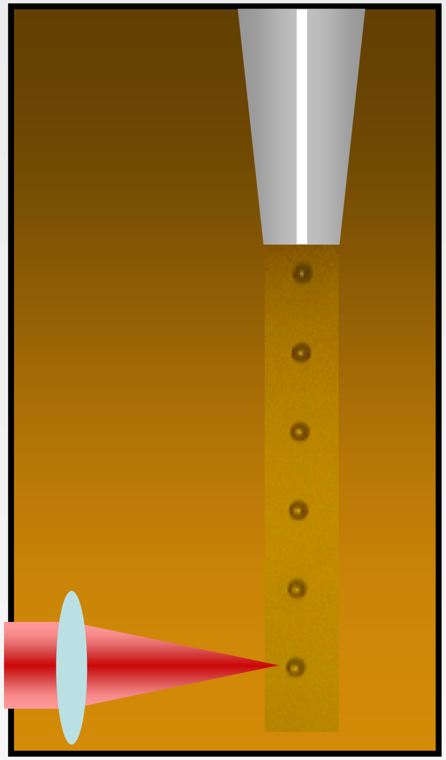
Tin



- Debris is the issue

Courtesy of G. O'Sullivan (Univ. College Dublin)
R. Faulkner (UCD Ph.D, 1999)
A. Cummings (Nahond Univ. Ireland)

The UCF tin-doped droplet source



Martin Richardson

K. Takenoshita, C-S Koay, S. George, T. Schmid, S. Teerawattansook R. Bernath, C. Brown

Laser Plasma Laboratory
College of Optics and Photonics & CREOL, UCF

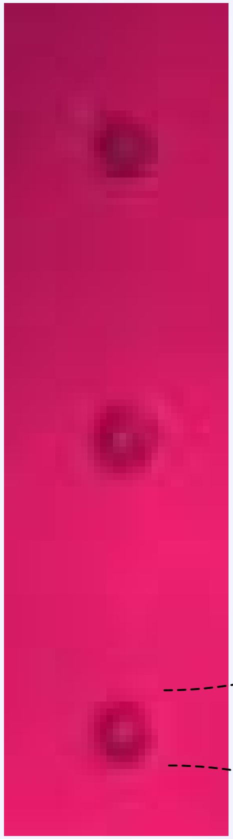
Moza Al-Rabban
Qatar University

Howard Scott
Lawrence Livermore National Laboratory

Vivek Bakshi
SEMATECH

Funded by SEMATECH, SRC Intel and the State of Florida

The tin-doped droplet laser plasma EUV source



Multi-component 30 -35 um diameter target at 30 kHz -- Location precision 3 um

Modest laser intensities I ~ 10^{11} W/cm^2

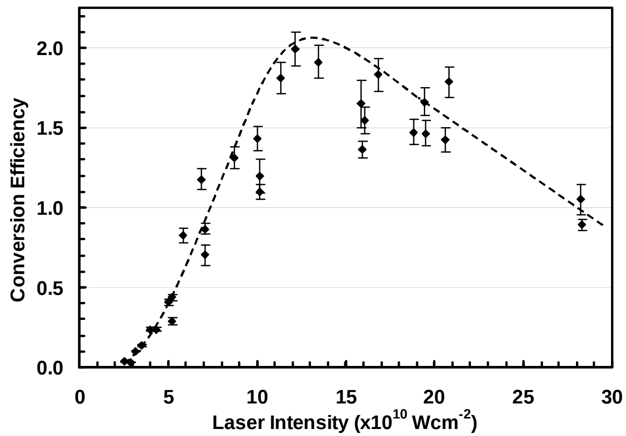
Mass-limited targets

Target contains only 10^{13} tin atoms

Recently demonstrated 30 kHz laser droplet irradiation with intelligent feedback beam and target control – continuous operation for 8 hours

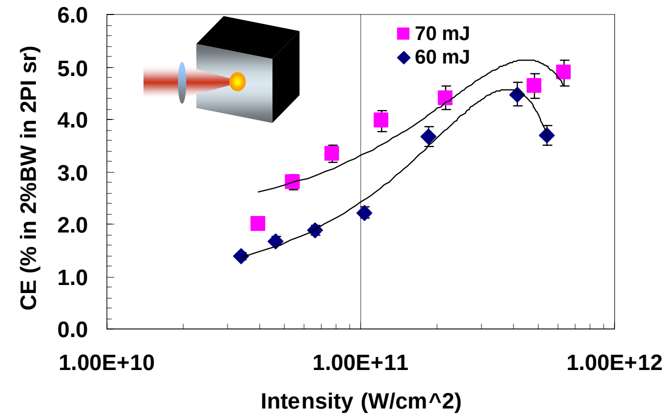
High CE demonstrated with Droplet Target

CE = 2% at 13.5 nm for tin-doped droplet target source



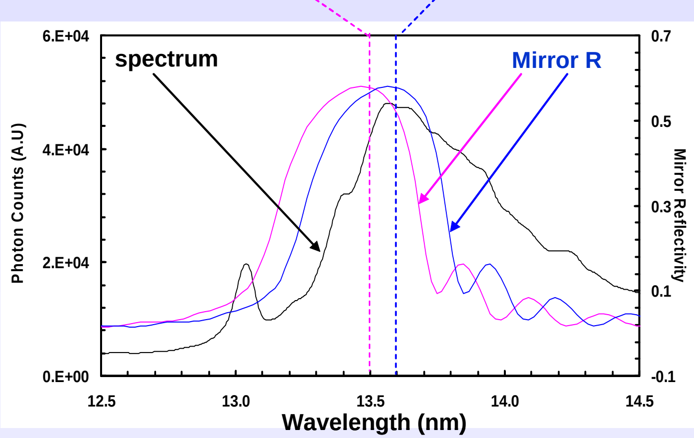
FOM FC2 team
F. Bijkerk S.A. vd Westen C. Bruineman

CE = 5.5 % with solid tin!



at 13.5nm, CE = 2%

at 13.6nm, CE = 2.25%

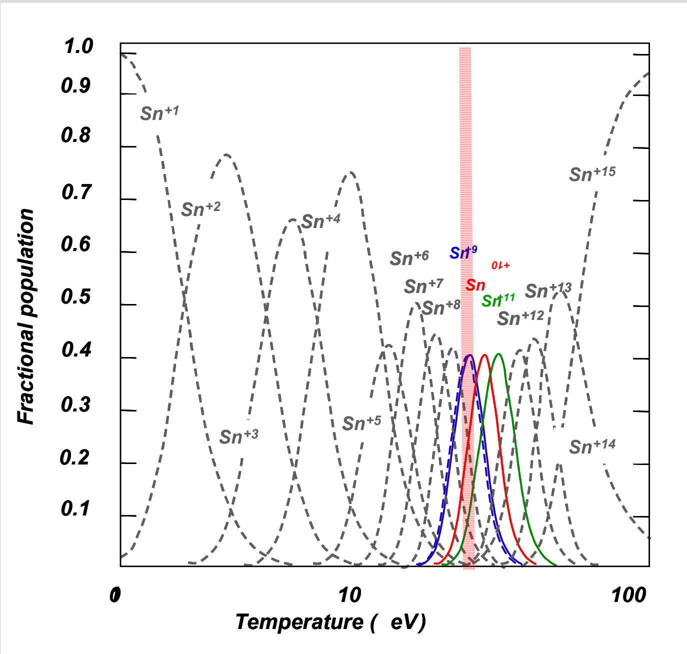


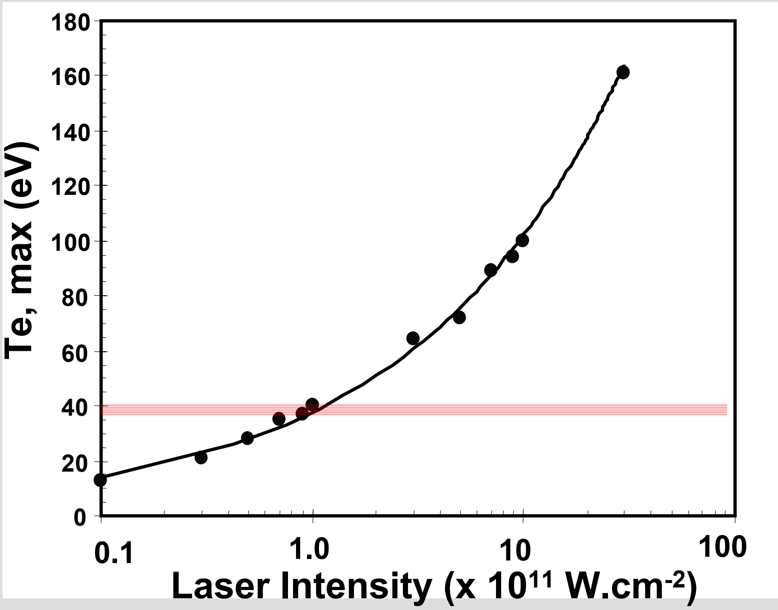
CE = 3% achievable with droplet source

--- for 30 kHz, 140 mJ laser

→ 120 W / 2π

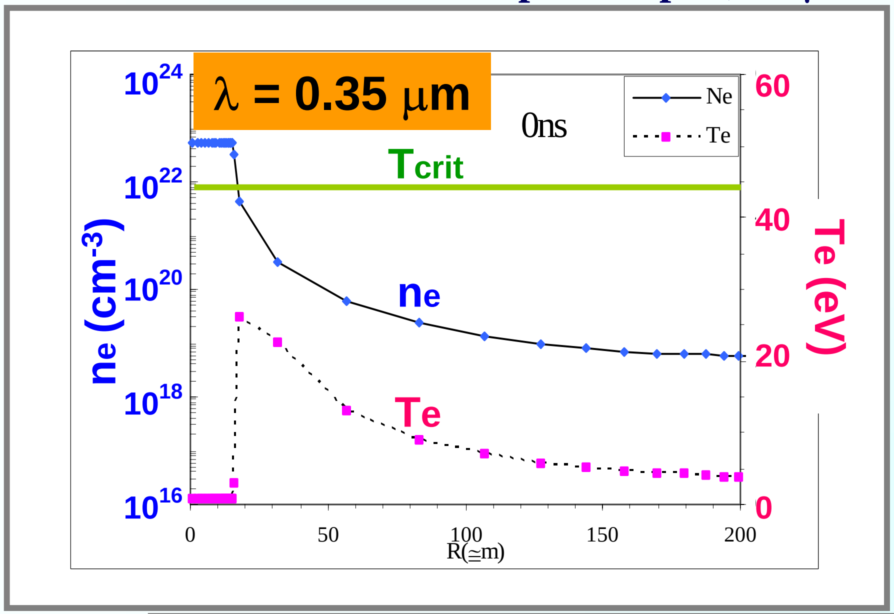
We can now manipulate the UTA emission spectrum

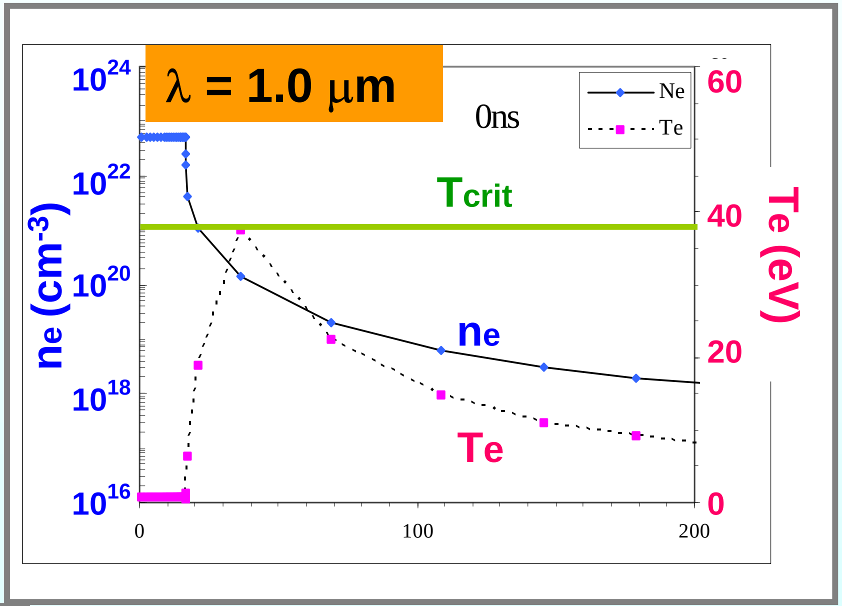


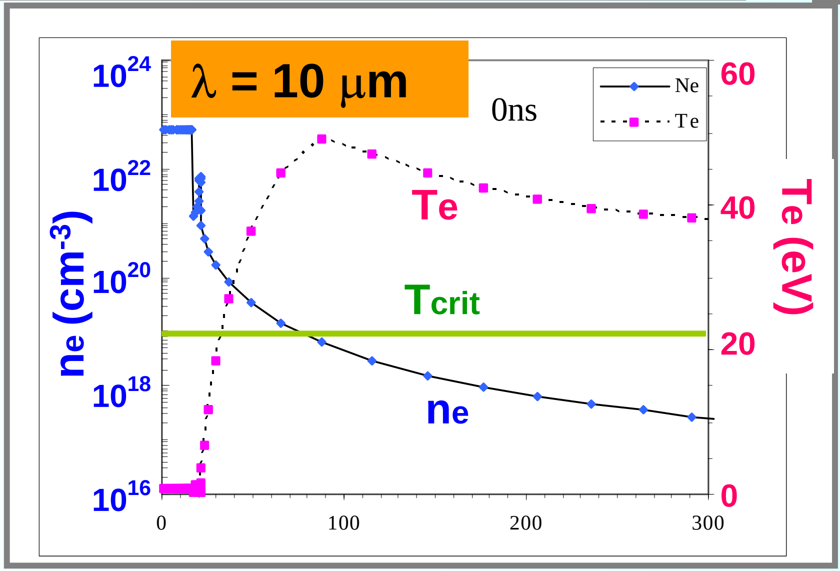


Conversion efficiency - Tin with other laser wavelengths

Condition: Tin-doped droplet, 35 μm dia, 10ns pulse, $I = 1.0 \times 10^{11}$ W/cm^2







0.35μm: Te - Higher laser intensities required

10μm: -Emission comes from lower n_e region

Summary

Multi-component droplet laser plasma droplet plasma

30 kHz laser irradiated droplet system demonstrated

CE = 2.3% with a droplet – 5.5 % (solid tin) - > 3% possible

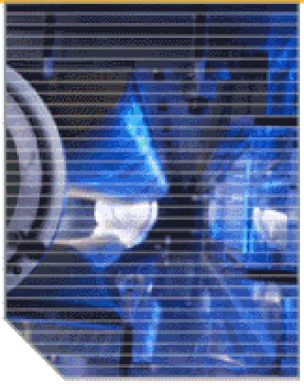
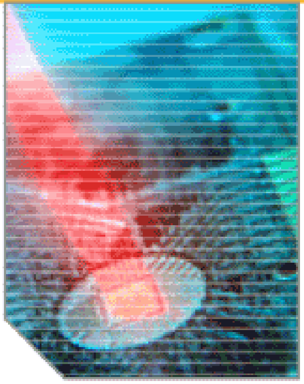
Droplet has only 10^{13} per target

Low energy ions only at mirror – no anomalous fast ions

Repeller Field stops both ions AND particles

Combination of mitigation schemes should provide enough mirror protection

Laser Produced Plasma Source System Development

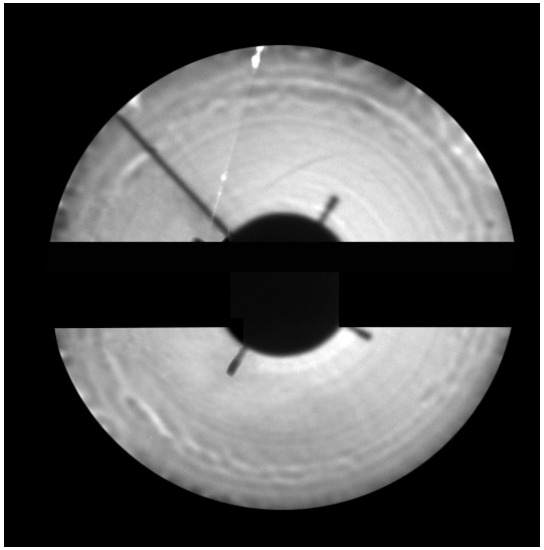




Sematech EUVL Symposium 2008

David C. Brandt*, Igor V. Fomenkov, Alex I. Ershov, William N. Partlo, David W. Myers, Georgiy O. Vaschenko
Oleh V. Khodykin, Alexander N. Bykanov, Jerzy R. Hoffman, Christopher P.Chrobak, Norbert R. Böwering
Shailendra Srivastsava, David Vidusek, Silvia De Dea, Richard Hou

Laser Produced Plasma EUV Source Development Continues on Schedule

Manufacturing Bay #1



EUV Far Field Image after 8 hrs

Source System Sub-Technologies

- High Power CO_2 Laser
- High Reflectivity MLM Collector
- Liquid Sn Droplet Generation
- Debris Mitigation / Collector Lifetime
- Vacuum Technology
- Beam Transport and Focusing
- Droplet Targeting Control
- Intermediate Focus Protection
- Plasma and Intermediate Focus Metrology
- System Control and Scanner Interface

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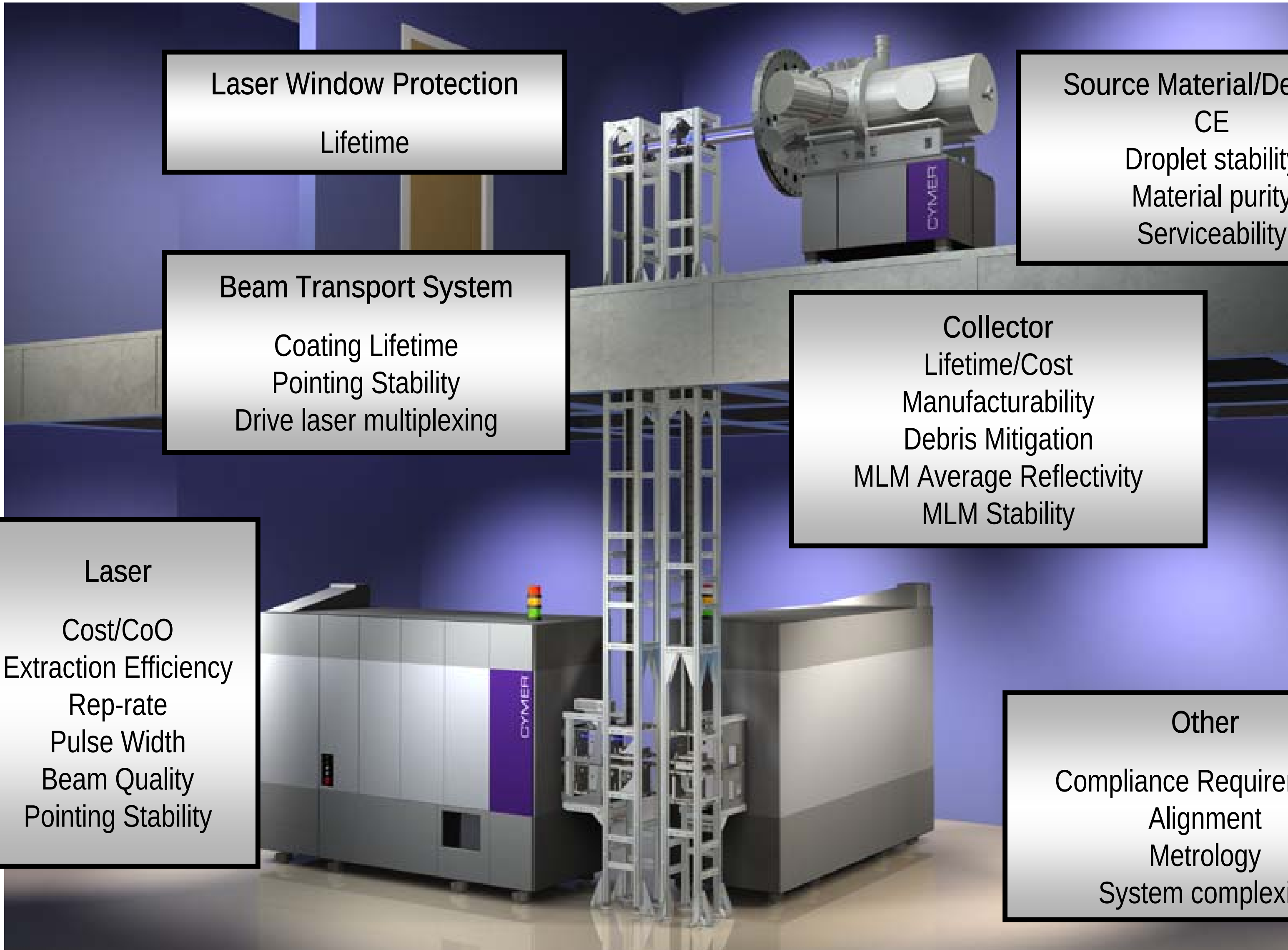
Development of a Laser Produce Plasma EUV Source has Significant Challenges



Laser Window Protection

Lifetime

Beam Transport System

Coating Lifetime
Pointing Stability
Drive laser multiplexing

Laser

Cost/CoO
Extraction Efficiency
Rep-rate
Pulse Width
Beam Quality
Pointing Stability

Source Material/Delivery
CE
Droplet stability
Material purity
Serviceability

Collector
Lifetime/Cost
Manufacturability
Debris Mitigation
MLM Average Reflectivity
MLM Stability

Other

Compliance Requirements
Alignment
Metrology
System complexity

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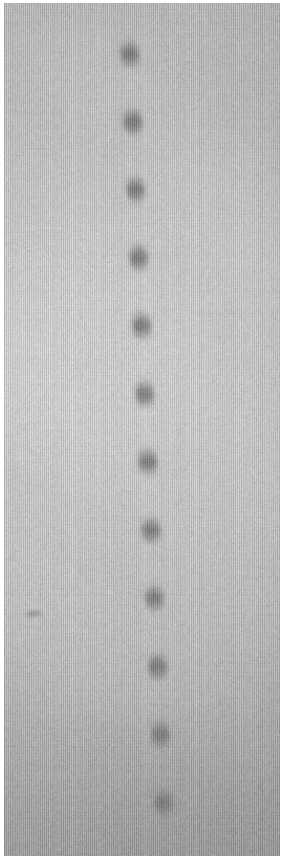
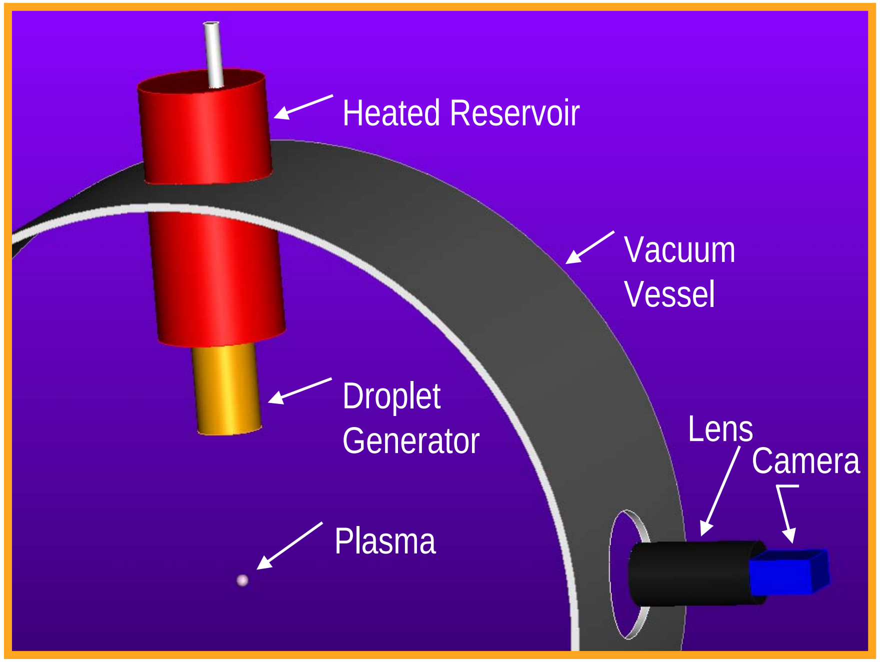
Liquid Metal Droplet Generator Developed



100 μm Sn droplets at 36 kHz, captured using strobe lighting



- Continuous stimulated droplet generation of liquid metals (Li and Sn) at temperatures up to 250°C
- Droplets diameter $\leq$100 μm
- Droplet rates up to 48 kHz
- Working distance of 50mm

Ref: Poster #5751-108, Algots, Cymer

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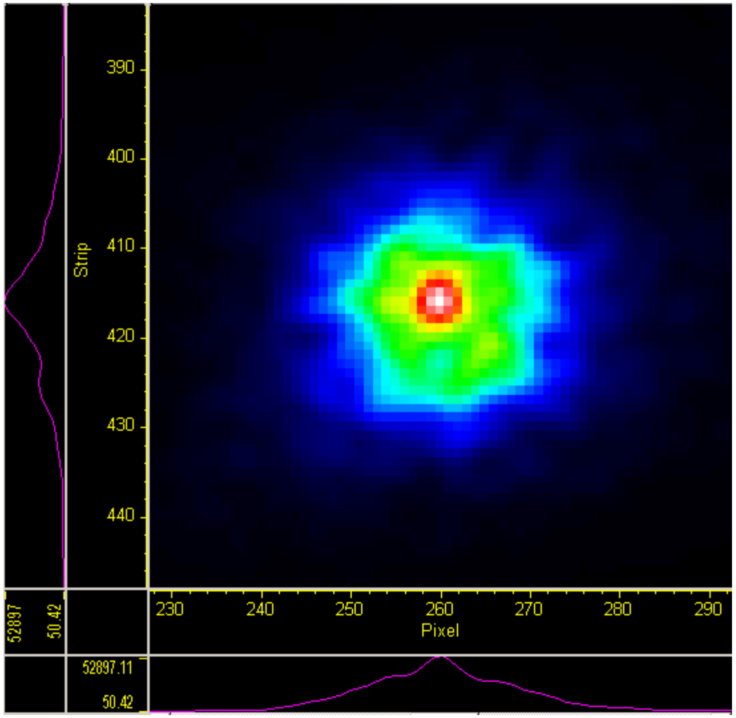
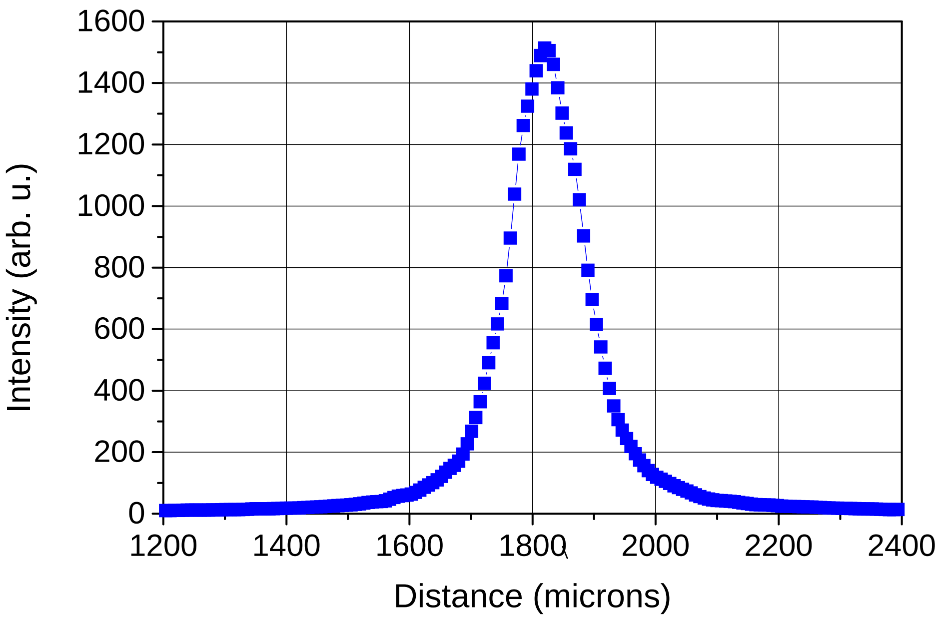
Size of EUV Emitting Region, 100W Bursts, 50kHz

EUV source size from in-band pinhole camera measurements viewing the plasma source at 90° angle



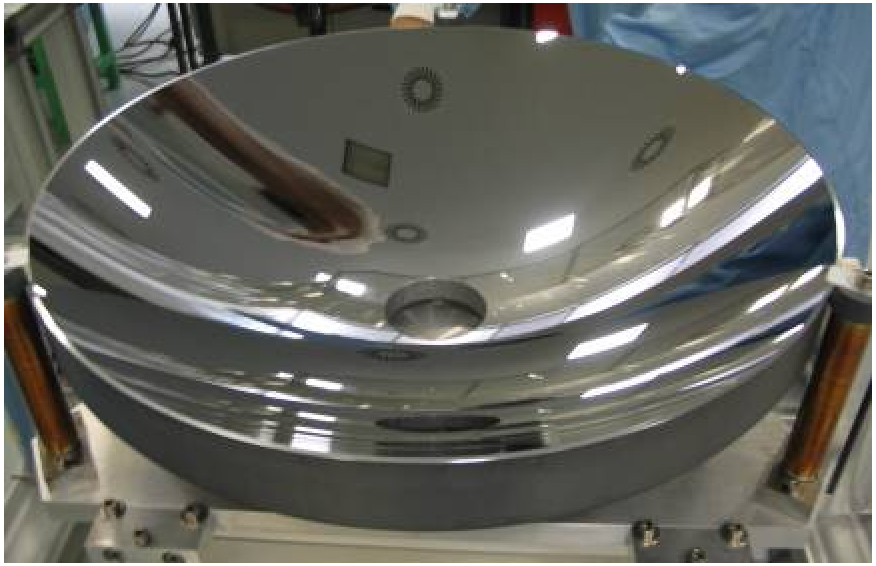
90 µm (FWHM)

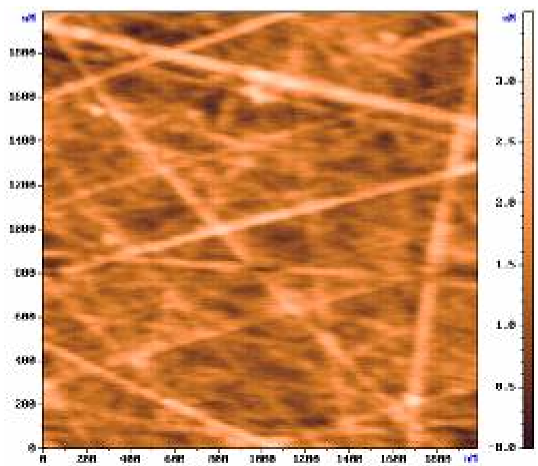
210 µm ($1/e^2$)



Intensity Profile

Multiple 5 sr Collection Optics in Final Stages of the Manufacturing Process



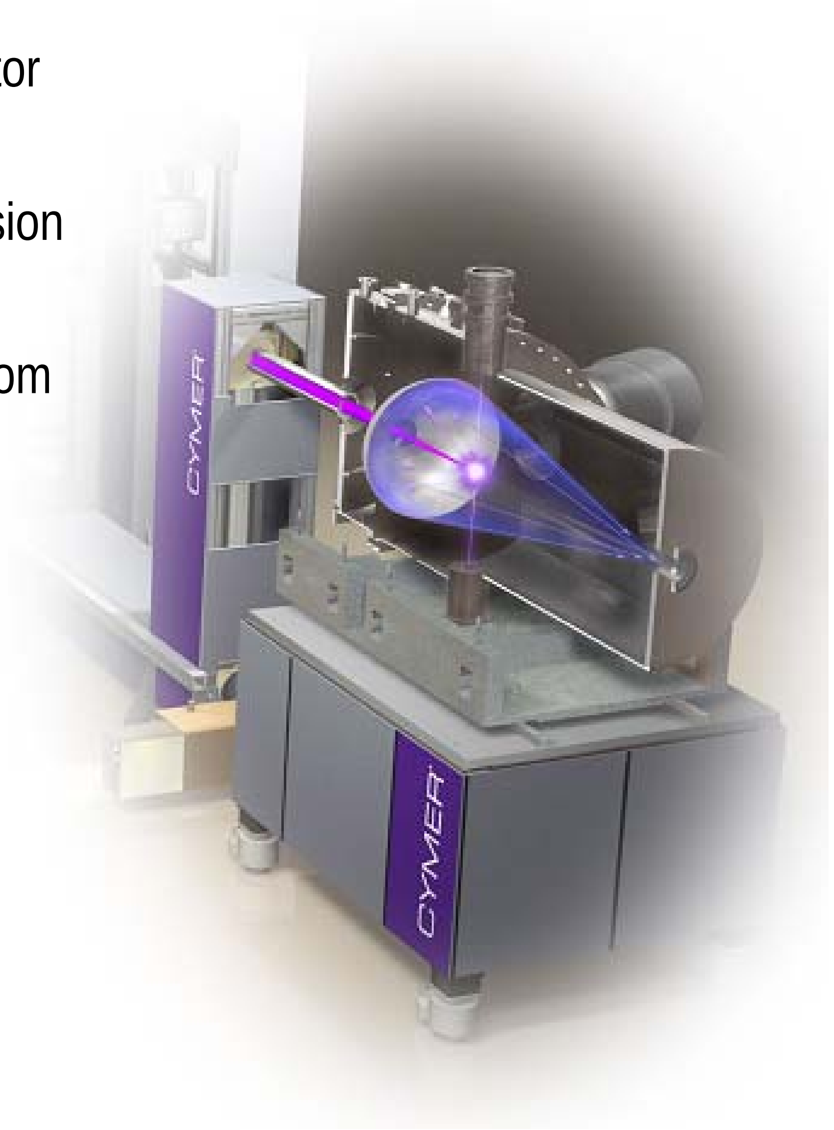


AFM measurements
1.8 µm x 1.9 µm
0.452 nm RMS

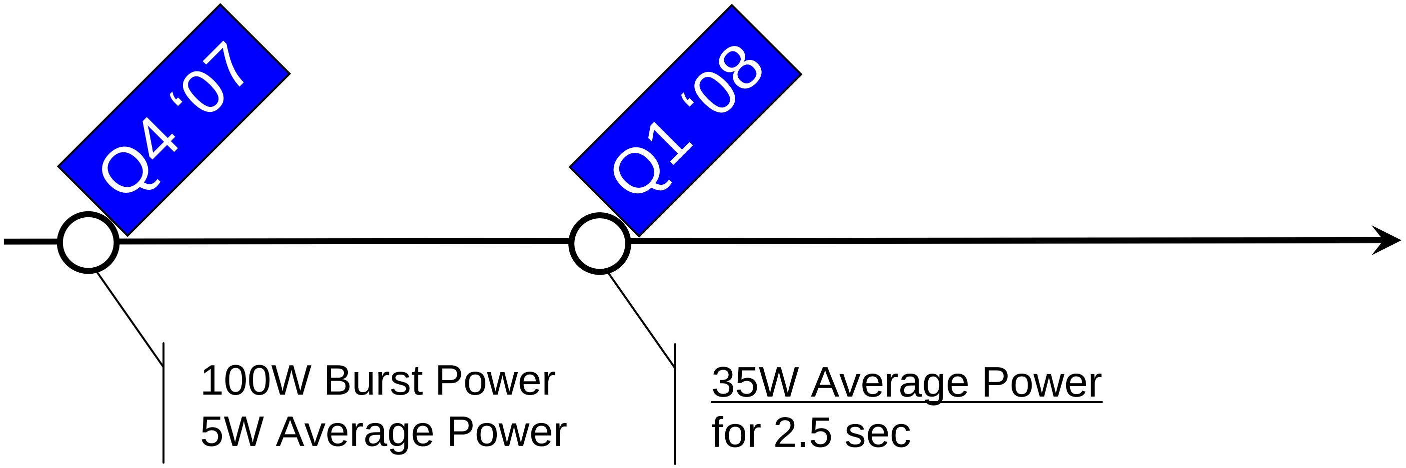
- Manufacturing processes
  - Blank machining
  - Shaping the figure
  - Coarse polishing
  - Super polishing
  - MLM coating
  - Reflectivity measurement
- Coated Collector expected to be integrated into first LPP system in Q4
- Good High Spatial Frequency Roughness (HSFR) is required for high reflectivity

Collector Lifetime Challenges

- Source material buildup on Collector
- Sputtering of MLM
- Source material implantation/diffusion into MLM
- Deposition of material sputtered from source hardware
- Deposition of source material contaminants
- EUV induced carbon growth and oxidation
- Thermal stability of MLM

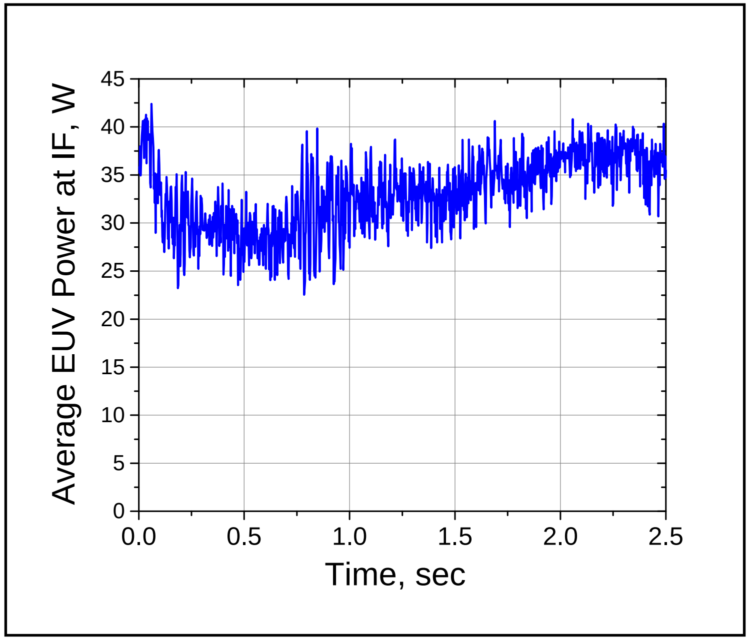


35W Average Power Demonstrated in Q1 2008



In Q1 08 the average power was increased to 35W

- Duration was limited to 2.5 seconds
- No collector was used, power measured at plasma



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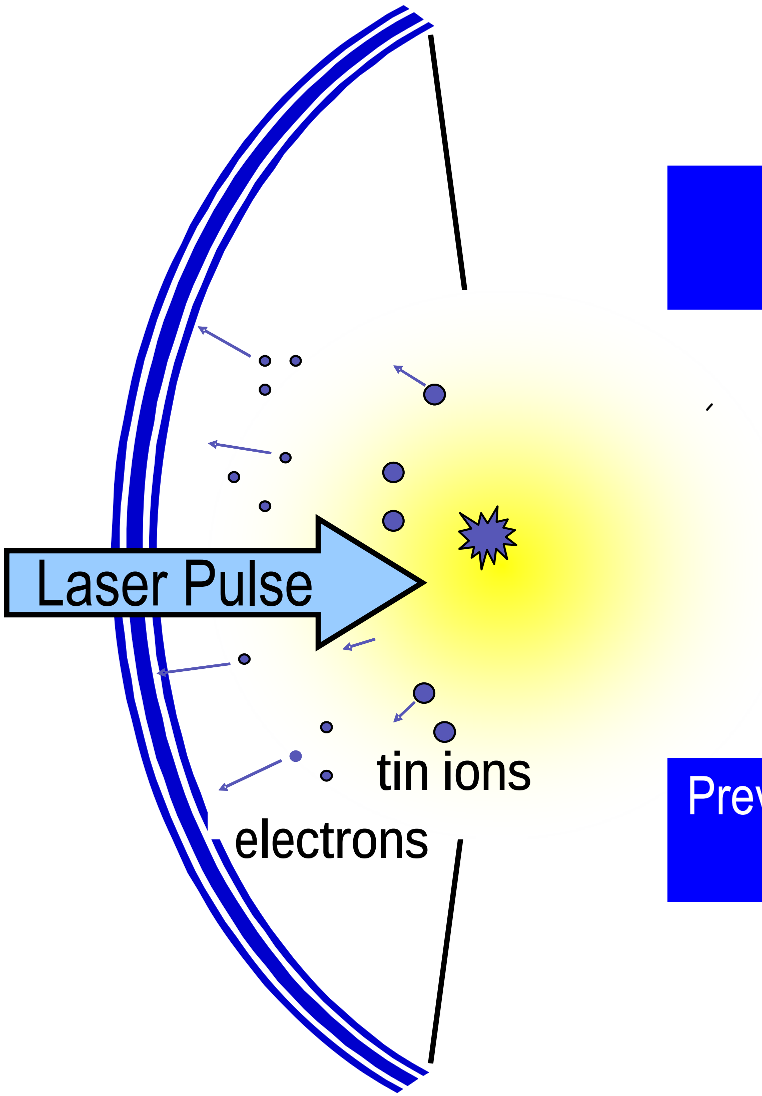
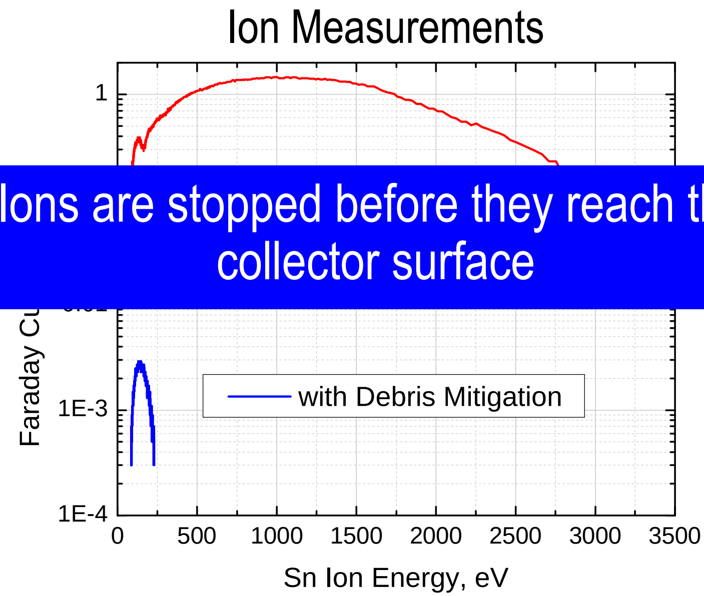
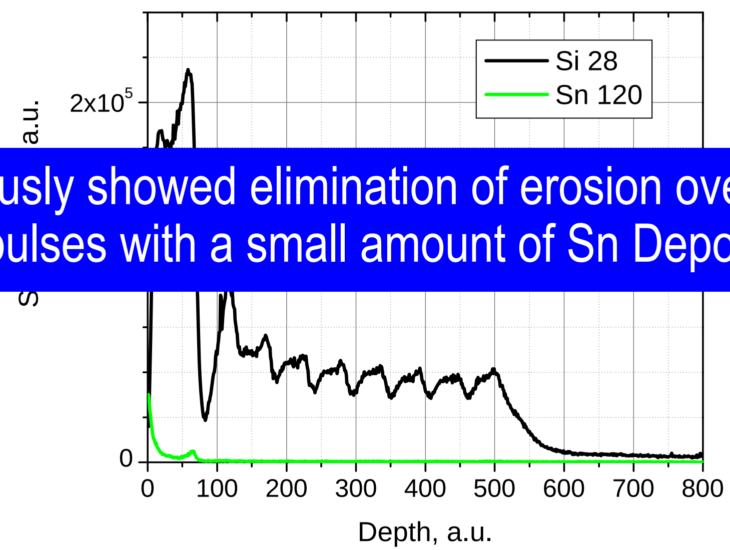
Debris Mitigation Stops Erosion from Ions





Sn Ions are stopped before they reach the collector surface

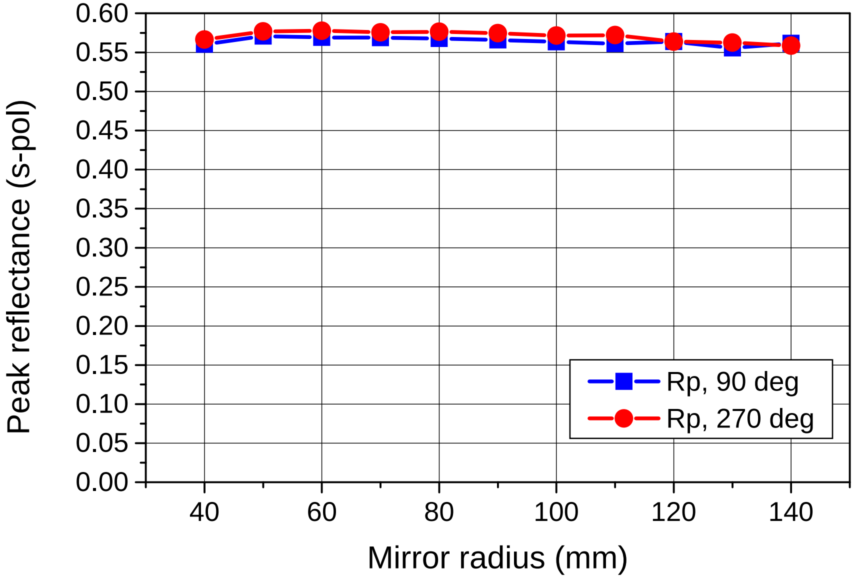


Previously showed elimination of erosion over 3 Mpulses with a small amount of Sn Deposition

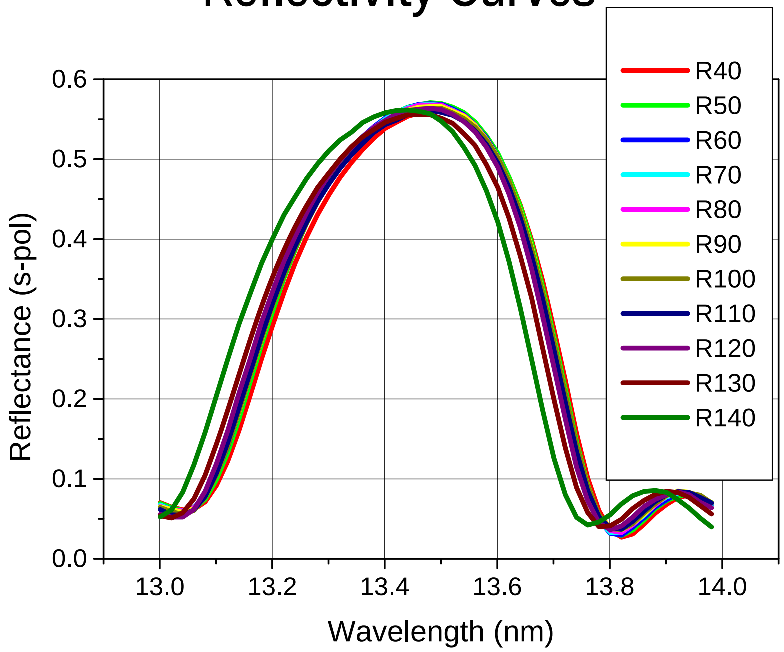
All measurements taken at collector surface

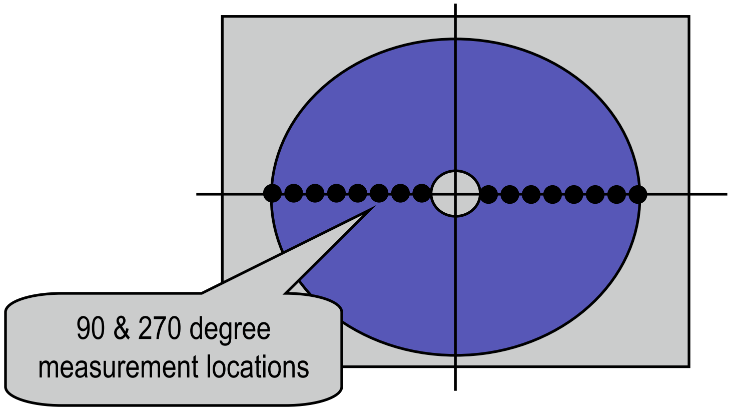
Diffusion Barrier MLM Coating EUV Reflectivity

Peak Reflectance



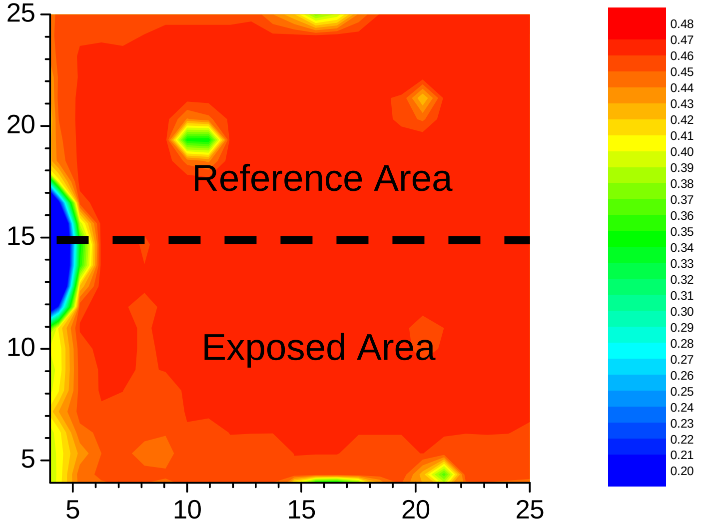
Reflectivity Curves



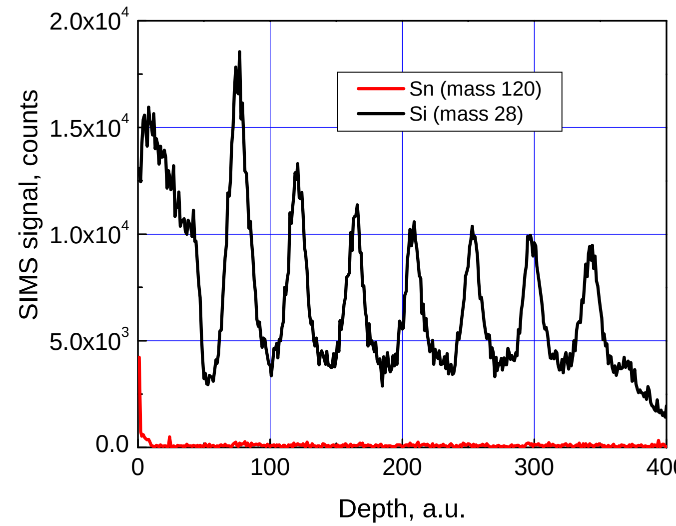


- 57% EUV peak reflectivity measured
- Graded coating with diffusion barrier layers for high temperature stability
- EUV measurements made at PTB

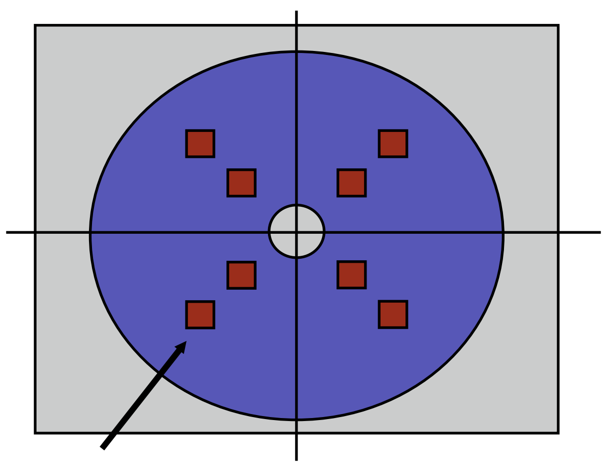
Exposure of Witness Samples Shows No Degradation of MLM Coating



2D EUV Reflectivity Map



8 Layer MLM Sample Post Exposure

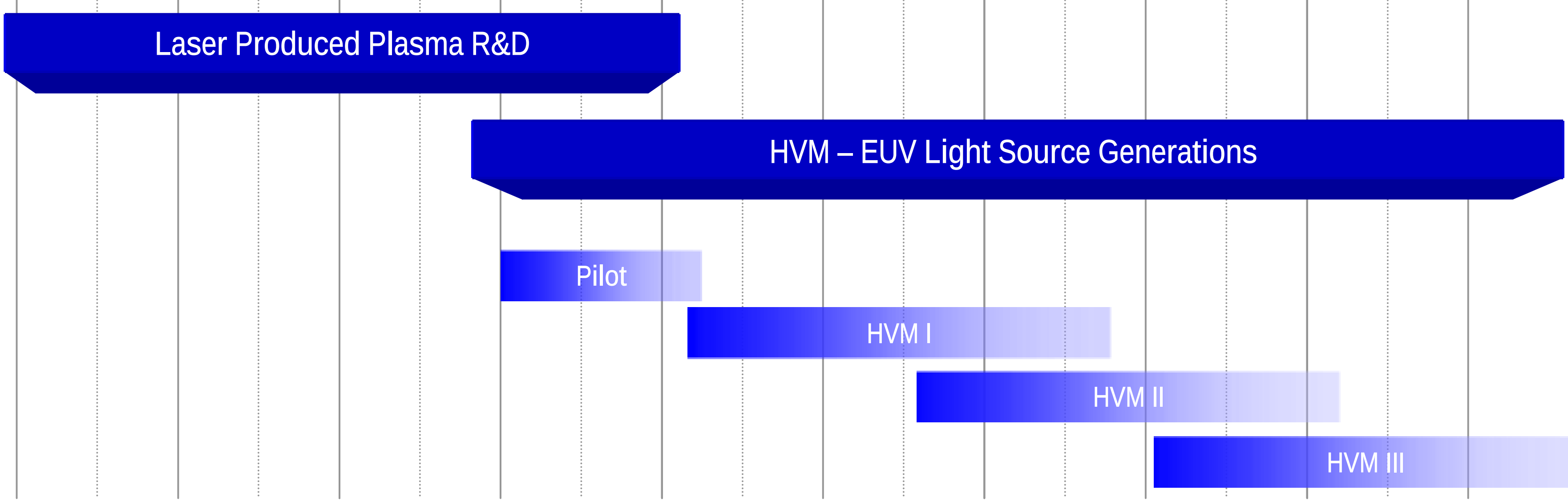


Position of Witness Samples on Test Collector

- 2D reflectivity maps shows <1% between exposed and reference areas
- SIMS analysis of 8 layer sample shows no erosion from ions
- Exposure parameters
  - 2 hours exposure
  - 60W / 10% duty cycle
- Reflectivity measurement from NIST

LPP EUV Source Roadmap

EUV Source Power Roadmap	Pilot	HVM I	HVM II
Drive laser power (kW)	**11**	**19**	**>20**
In-band CE (%)	3.0	3.5	4.0
Collection Efficiency (sr)	5	5.2	5.5
Collector Reflectivity (%)	>60	>60	>60
Optical Transmission (%)	80	85	90
Total EUV power at IF (W)	**>100**	**>200**	**>400**



Summary

- Cymer continues to meet it's EUV source development schedule
- Manufacturing of first pilot systems is in progress
- Run time up to eight (8) hours with stable performance demonstrated
- Debris Mitigation effectivity demonstrated to protect the collector from erosion due to ions and Sn deposition
- Integrated system testing with 320mm (1.6sr) collector has shown stable transmission of EUV power to the far field and good distribution of EUV energy
- Cymer is committed to commercializing an HVM EUV light source for the sub-32nm node

CYMER

PHILIPS

ILT
Fraunhofer Institut Lasertechnik

XTREME technologies

PHILIPS

Philips's EUV Source:

Update and Issues

J. Pankert,
EUV Source Workshop
San Jose 2005

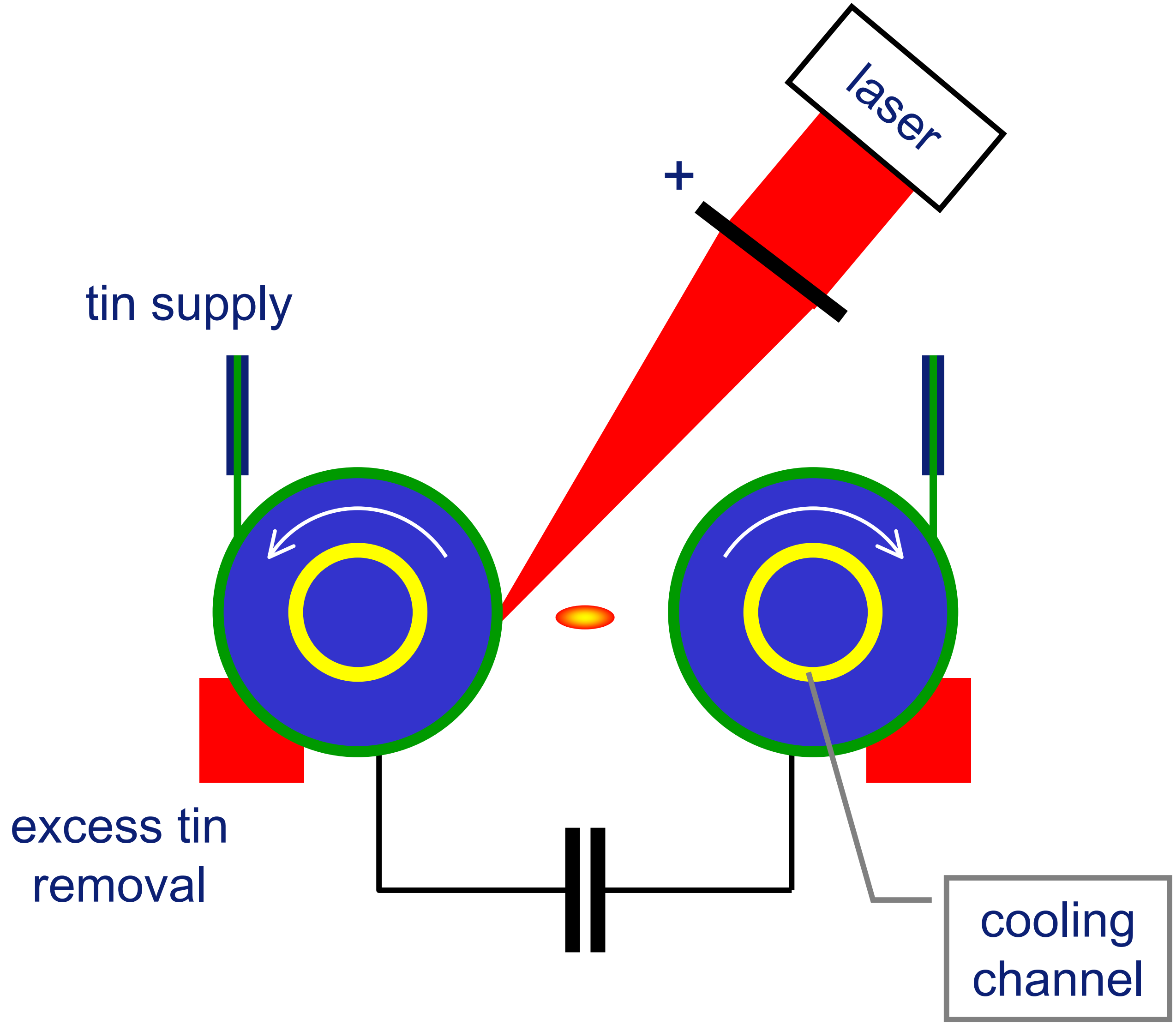
Sn DPP source-collector modules:

Status of Alpha sources,
Beta developments, and
HVM experiments

SPIE Advanced Lithography
San Jose, February 24, 2009

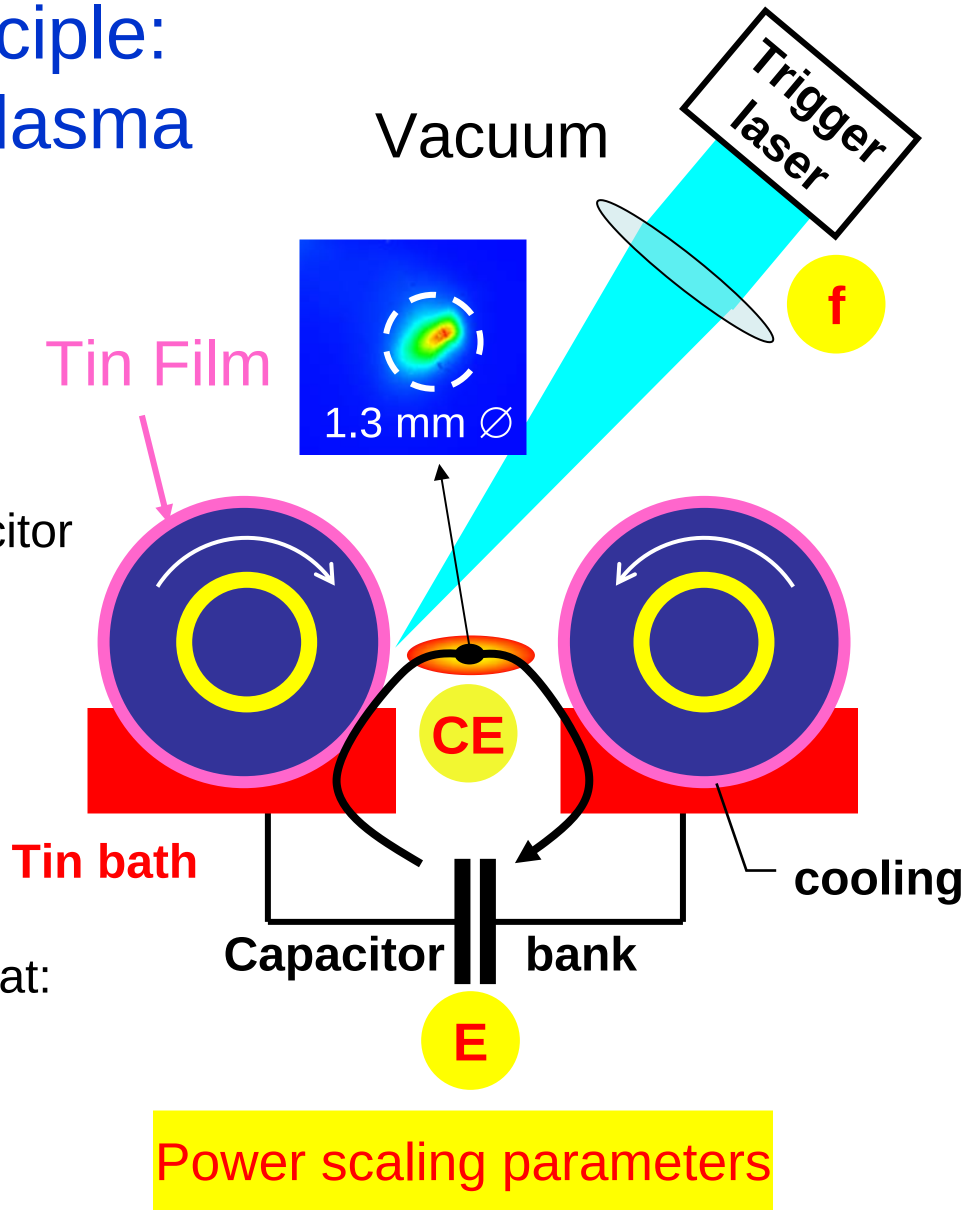
Marc Corthout, Masaki Yoshioka, et al.

Schematics of the source

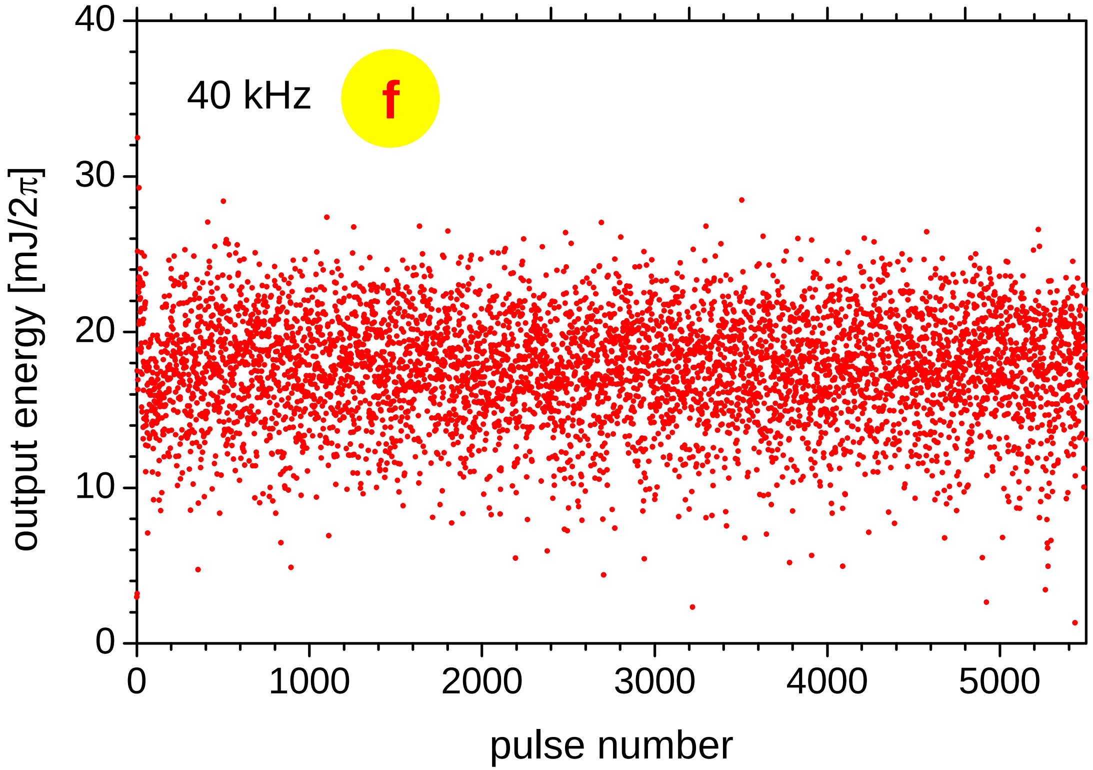


Basic light generation principle: Sn *Discharge* Produced Plasma using rotating electrodes

- Laser Triggered Vacuum Spark
- Electrical contact through tin
  - Simple power supply to load capacitor bank
- Regenerating liquid tin surface
  - Electrode erosion problem fundamentally solved !
- Liquid metal cooling with tin
  - Very efficient to remove excess heat: >>100kW input power



Fast plasma decay time enables continuous operation



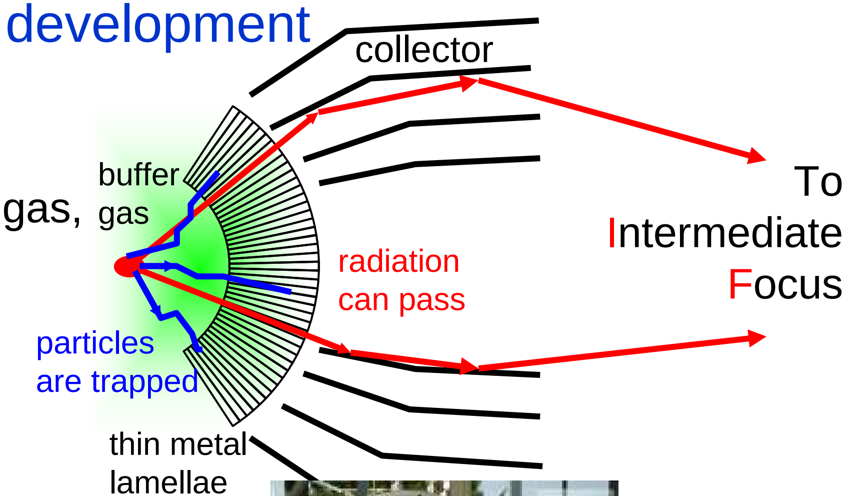
5500 pulses at **40kHz** continuous operation without power loss

Summary of the properties

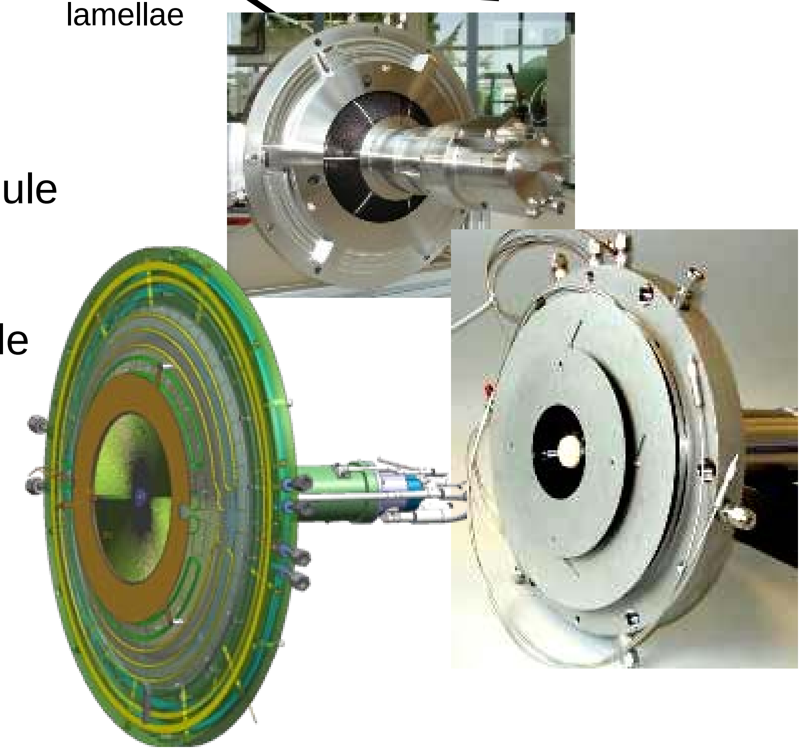
- Electrodes
  - Rotating: scalability to very high powers
  - Regenerative electrodes:
    - Liquid tin surface
    - Erosion problem fundamentally solved
- General properties
  - CE 2%
  - Pinch size < 1mm
  - 5 kHz demonstrated
  - 120 W continuous operation
  - 260 W short term (limited by vacuum vessel)

Sn Debris Mitigation Generations:
running for many years parallel to source development

- **Basic Principle: Use of a Foil Trap**
  light passes through foils,
  particles are trapped after collisions with buffer gas,
  protecting the collector

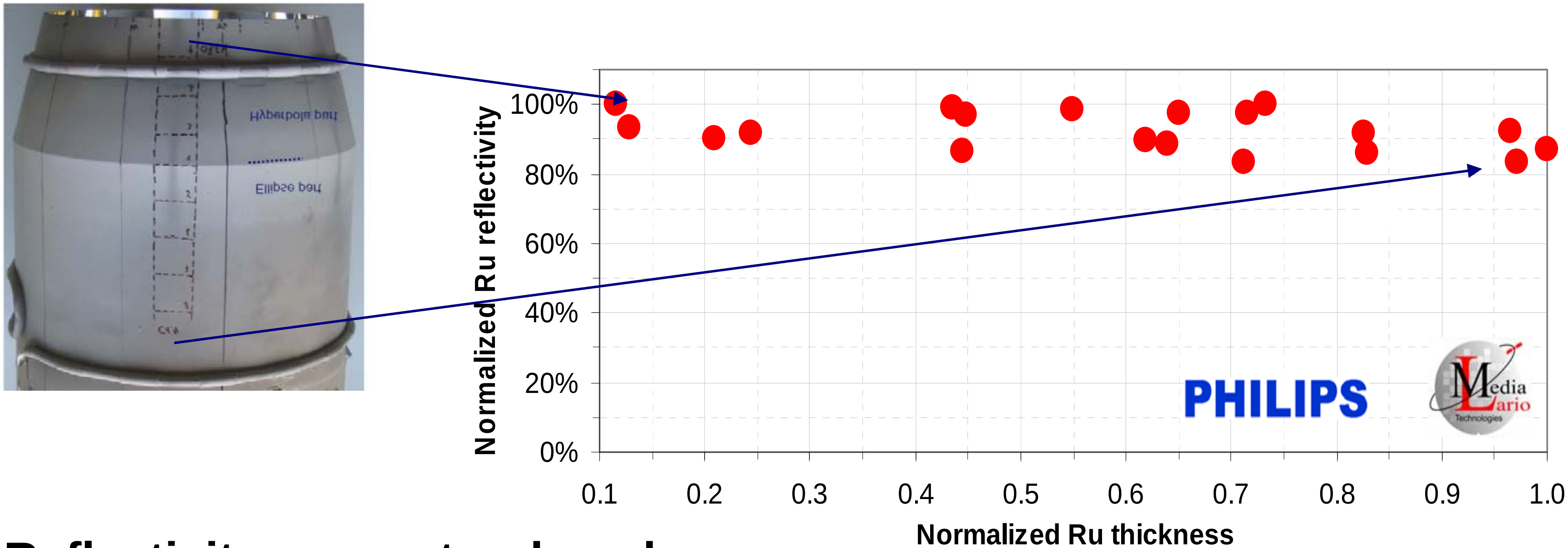


- 2004 V0 Introduction of current DM concept
  - experiments for proof of concept
- 2005 V1 DM system for research tool
  - experiments for debris mitigation with samples
- 2006 V2 DM system for Sn-SourceCollectorModule
  - experiments for debris mitigation with collector shells
- 2007 V3 DM system for full Alpha collection angle
  - advanced system for high power (>170 W source)
  - long life and efficient water-cooling solution
- 2008 V4 DM system for Beta collection angle
  - further improvement of mitigation efficiency
  - beta source power levels



Collector Lifetime

Collector exposed for weeks has been cut in samples and analyzed



Reflectivity was not reduced:

--> Sn deposition was negligible due to very efficient mitigation

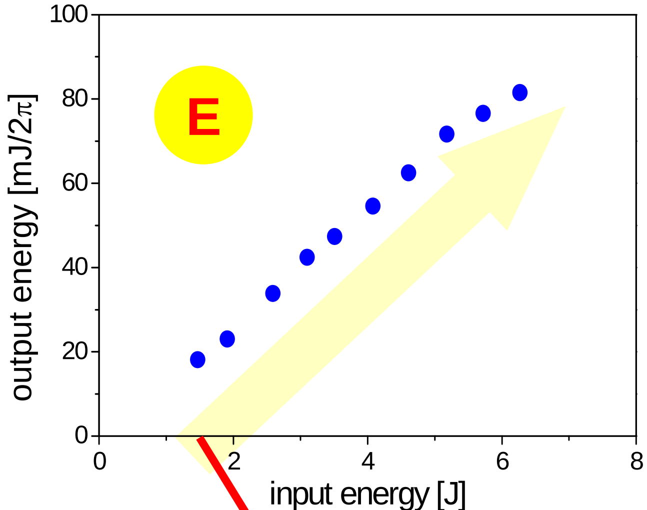
--> Sputtering of reflective Ru layer was observed:

Ru coating of Grazing Incidence collector works as sacrificial layer keeping full reflectivity despite significant material removal

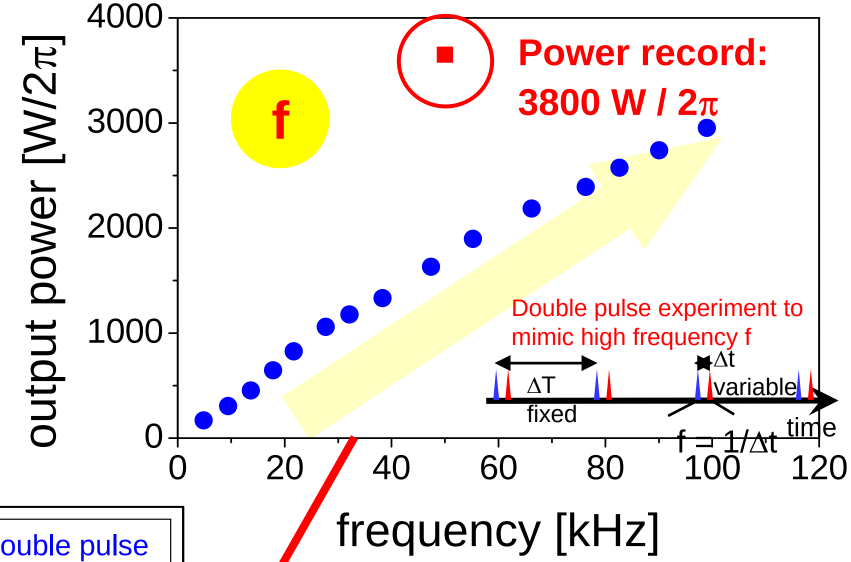
For more details see the Media Lario presentation later in this session

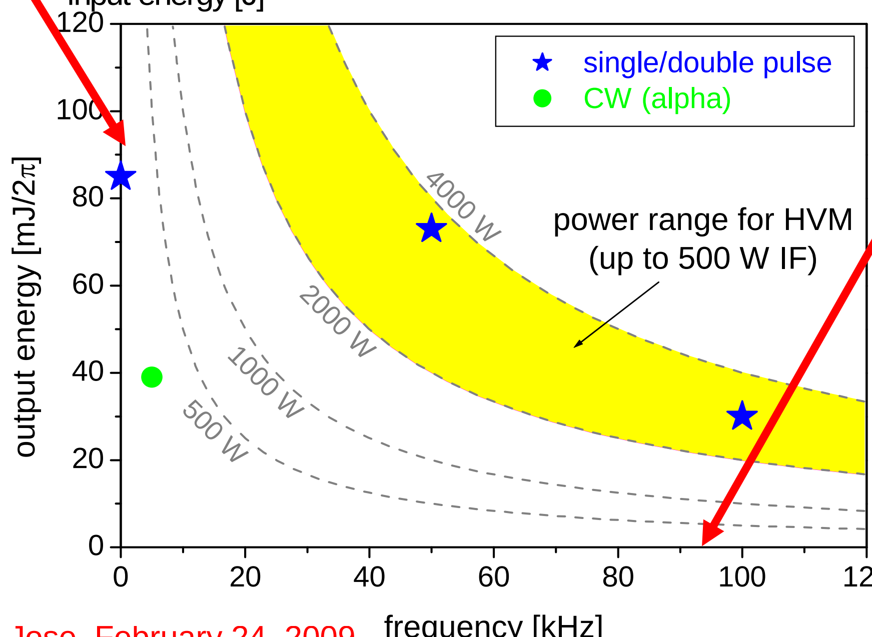
Power scaling of Sn-DPP enables HVM power

Energy scaling to above 80 mJ per pulse



Frequency scaling to 100kHz



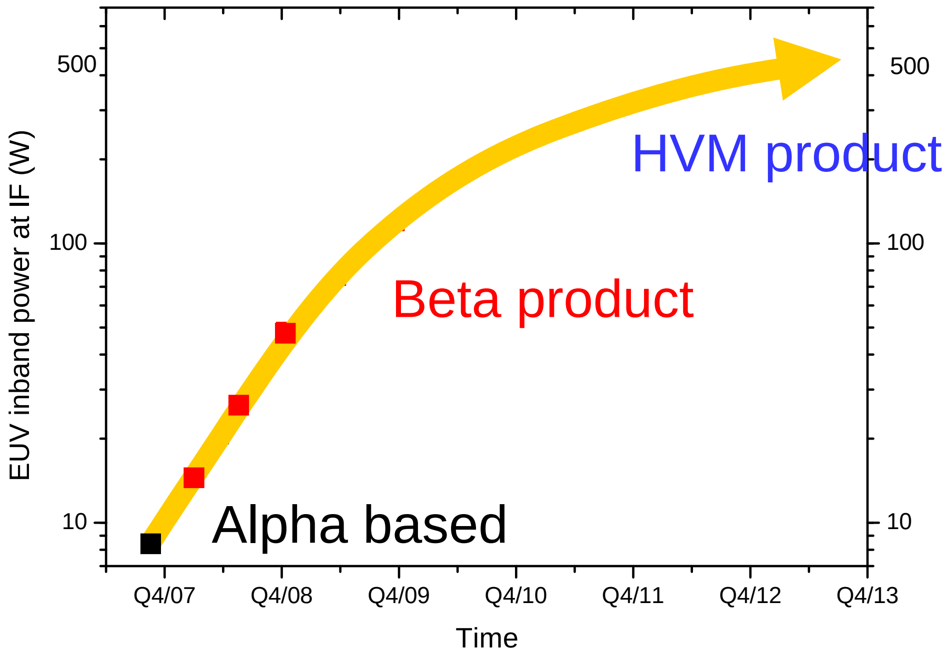


Energy and frequency scaling without losing efficiency

HVM requirements are in scalable Sn-DPP range

See also Erik Wagenaars et. al, Appl. Phys. Lett. **92** 181501 (2008).

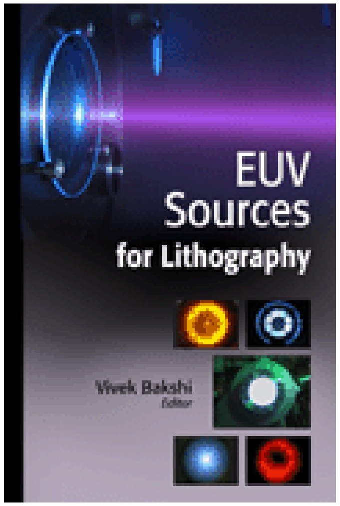
IF power roadmap is on track



- **All power values are measured under continuous operation with 100 % duty cycle**

- **2pi powers are transferred to IF powers with 10% CoMo transmission from our experimentally verified CoMo throughput**

EUV Sources for Lithography (SPIE, November 2005)
Vivek Bakshi, Editor

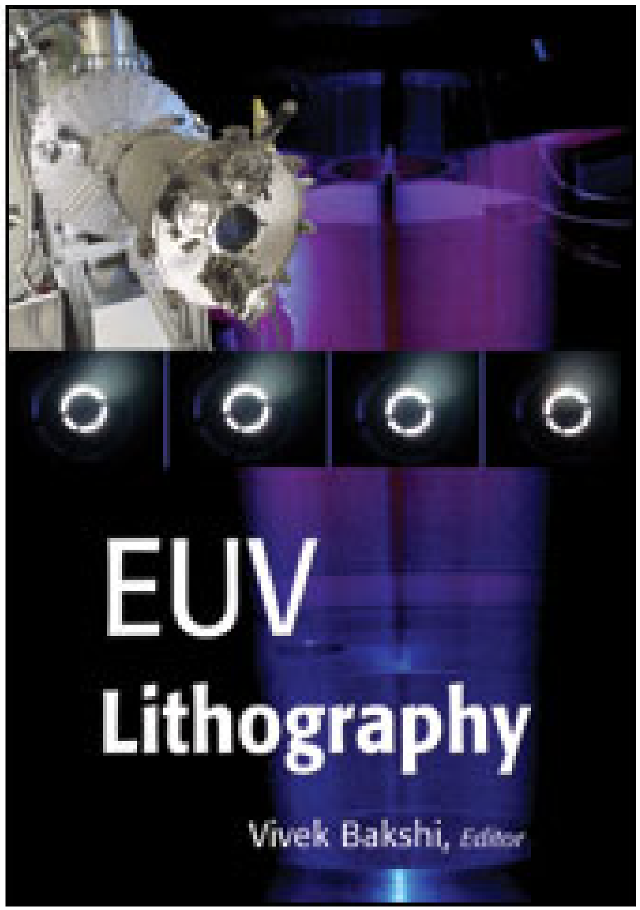


This comprehensive volume, edited by a senior technical staff member at SEMATECH, is the authoritative reference book on EUV source technology. The volume contains 38 chapters contributed by leading researchers and suppliers in the EUV source field. Topics range from a state-of-the-art overview and in-depth explanation of EUV source requirements, to fundamental atomic data and theoretical models of EUV sources based on discharge-produced plasmas (DPPs) and laser-produced plasmas (LPPs), to a description of prominent DPP and LPP designs and other technologies for producing EUV radiation. Additional topics include EUV source metrology and components (collectors, electrodes), debris mitigation, and mechanisms of component erosion in EUV sources. The volume is intended to meet the needs of both practitioners of the technology and readers seeking an introduction to the subject.

Prices: $127 / $150 (SPIE Member/List)
(Available November 2005)

EUV Lithography

Vivek Bakshi, Editor



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Volume 31

Vacuum Ultraviolet Spectroscopy I

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